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Wat. Sci. Tech. Vol. 26, No. 7-8, pp. 1583-1591, 1992.
Printed in Great Britain.

0273–1223/92 $15.00

AGRICULTURAL AND MUNICIPAL USE OF WASTEWATER

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ABSTRACT

Areas in relatively dry climates often have water shortages and there is competition between municipal and agricultural (irrigation) water use. The problem can be alleviated by using the water twice, first for the cities and then for agriculture after the municipal wastewater has been properly treated. There are now two sets of water quality standards for irrigation with wastewater: a stringent set for developed countries, and a less stringent set for developing countries. Also, more and more cities will have to use their wastewater internally for irrigation of parks, etc., and even for drinking. The latter requires advanced wastewater treatment. Part of this treatment can be supplied inexpensively by a groundwater recharge and recovery system, which also provides storage and enhances the aesthetics of direct potable reuse of wastewater by breaking the pipe-to-pipe connection. The renovated water from a recharge or "soil-aquifer treatment" system generally can be used as such for unrestricted irrigation, but potable use requires additional treatment.

KEYWORDS

Wastewater use; water reuse; irrigation; potable recycling; water quality standards; treatment; groundwater recharge; soil-aquifer treatment.

HISTORIC PERSPECTIVES

There was a time when human and other wastes were simply thrown out of the window. The only environmental concern then was a direct hit on the people in the street. Thus, as a courtesy to passersby, the thrower yelled "gardez l'eau" (watch out for the water)! This term was anglicized to gardyloo which is now the name of a British ship for ocean dumping of municipal sludge! From the streets, the waste could readily run into streams or other surface water, along with raw wastewater from the early sewers. The discovery that wastewater contamination of drinking water was the main cause of disease outbreaks like cholera and typhoid then made it necessary to keep wastewater out of the surface water, since adequate treatment technology had not yet been developed. This led to the establishment of "sewage farms" around many of the cities. Applying wastewater to land rather than discharging it into surface water was an early form of zero discharge!

In the early part of this century, disinfection of drinking water by chlorination was discovered and put into use. This gave the green light to a resumption of surface water disposal of wastewater, because now the surface water could be disinfected and microbiological contamination was no longer a health problem. Besides, the cities were growing and needed the land of the sewage farms around them for more streets and houses. At the same time, better wastewater treatment processes were developed and applied, primarily to prevent undue oxygen "sags" in the streams and not to exceed the "assimilative" and "self-purification" power of the receiving water. Removal of biochemical oxygen demand (BOD) and suspended solids (SS) were the main objectives. Then came the era of "better living through chemistry," causing more and more chemicals to enter wastewater through discharges from households, industries, hospitals, etc. This prompted the current interest in developing increasingly stringent standards for discharge of wastewater into surface water to prevent eutrophication and to protect aquatic life, recreation, and reuse opportunities of the water. This trend will undoubtedly continue until wastewater treatment becomes so expensive that municipalities will want to stop discharging their wastewater into surface water and use it themselves. When that happens, we have come full circle to zero discharge again!

If given a choice, most people prefer to live in relatively warm and dry climates. Witness, for example, the shift in population from snowbelt to sunbelt states in the United States and the retirement of Europeans in Mediterranean countries. Unfortunately, however, such areas tend to have limited water resources and their agriculture needs irrigation. This produces competition for water between urban and farming interests, especially during droughts. It will then be logical to let the cities have priority over the limited fresh water resources, and to use the municipal wastewater for agricultural irrigation. Wastewater may also be needed for park and landscape irrigation in the cities themselves and for certain industrial uses such as cooling for electric power generation. Ultimately, wastewater may have to be recycled for potable use, directly or indirectly, as some cities are already doing or planning.

AGRICULTURAL USE

Water conservation. Irrigated agriculture is the biggest consumptive user of diverted water in the world. Food production as a whole accounts for about 70% of the world's water use (Postel, 1989). About 17% of the world's cropland is irrigated and this produces about one-third of the global harvest. In areas with dry climates, crop irrigation often accounts for most of the water use (for example, between 80 and 85% of total water use in California and Arizona). Where there is not enough water for both municipal and agricultural use, the latter usually is reduced by water conservation or other means. The field efficiency of water use in irrigation is calculated as the amount of water used by the crop (evapotranspiration) divided by the amount of water applied to the field. This efficiency often is less than 60%, but it can also be more than 70%, depending on the type, design, and management of the irrigation system. Seepage losses from canals or other water conveyance facilities reduce the overall water use efficiency even more, as does evaporation from storage reservoirs. This has led many "urbanites" to argue that irrigation is an inefficient and wasteful use of water, and that all that needs to be done to save water in agriculture and to make more water available to cities is to increase the irrigation efficiency of the farmers' fields. Often, however, this is not true.

Low field irrigation efficiencies are due to excessive water application, which produces "deep percolation" below the crop root zone and/or runoff or "tail water" from the lower end of the field. However, deep percolation can go to underlying groundwater from where it can be pumped for further use, and tail water can be collected in ditches and used to irrigate lower fields. Thus, "one field's inefficiency is another field's water source." Because of this use of water losses, efficiencies of entire irrigated areas (valleys, basins, districts) are much higher than those of individual fields, i.e., as much as 90% or more, and improving field irrigation efficiencies will not save significant amounts of water. Increasing field irrigation efficiencies only saves water where deep percolation and tail water are not used again, for example, where there is no groundwater or the groundwater is too salty, or where tail water runs off into swamps, salt lakes, or other waste areas where it evaporates. Thus, where regional irrigation efficiencies are already very high, the only way to reduce the use of irrigation water is to reduce evapotranspiration. This can be achieved by reducing the irrigated area, by switching to different cropping systems (fewer warm season or summer crops and more cool season or winter crops), by growing more crops for direct human consumption instead of forage crops that are converted into meat and other animal products, by growing crops that are more drought-resistant, and by reducing evaporation from the soil (mulches, subirrigation). Reducing the irrigated area will reduce food production, unless crop production per unit area and crop water use efficiency are increased by using better agronomic practices. However, there are limits to how much crop yields can be increased and reducing irrigated areas ultimately will lead to reduced food production.

Irrigation with wastewater

Except for water used outside the home which eventually evaporates back to the atmosphere, municipal water use is essentially non-consumptive but it does, of course, degrade water quality. After suitable treatment, however, wastewater can be biologically (health aspects) and chemically (agronomic aspects) suitable for irrigation. Thus, where there is competition for water between agricultural and municipal uses, the problem can be solved by letting the cities use the water first, and then treating the wastewater so that it can be used for unrestricted irrigation. Unrestricted irrigation means that the farmer can use the water to grow any crop and to use any type irrigation system, including sprinkler irrigation of crops consumed raw or brought raw into the kitchen. Restricting irrigation to non-edible crops or forage crops to reduce wastewater treatment costs often is only feasible for relatively small farms or special farms where the cities have control over what crops are grown and how the wastewater is applied. Otherwise, a strong enforcement and control program will be required to make sure that farmers don't grow crops that are consumed raw. Where water is very critical, municipalities should minimize the outdoor use of water so that almost all the water that goes into the city flows out of it again as wastewater that can be reused. If water is considered a commodity that can be traded on the open market, farmers may wish to sell their irrigation water outright to the cities if this gives them more money then they can make by growing crops, regardless of whether they get it back as wastewater.

There are now two main public health water quality standards for unrestricted irrigation with municipal wastewater. One standard is for developed countries which are technically and financially capable of high technology treatment. The other is for developing countries which cannot afford expensive treatment and where stringent health standards would lead to no treatment at all and the use of raw wastewater for unrestricted irrigation, which of course is completely unacceptable. The standard for developed countries is patterned after California's Title 22 Effluent Reuse Standards (Bouwer and Idelovitch, 1987; Pettygrove and Asano,1985; Shelef, 1991), and calls for treatment of wastewater so that it is essentially free from pathogenic organisms (no fecal coliforms, no viruses, no eggs of parasitic worms) and has low turbidity (less than 2 turbidity units). This can be achieved with conventional primary and secondary treatment followed by coagulation, sedimentation, granular media filtration, and chlorination or other disinfection. Where hydrogeological conditions are favorable for groundwater recharge with infiltration basins, the movement of partially treated wastewater through soils and aquifers will clean the wastewater sufficiently so that it can be collected from the aquifer as such for unrestricted irrigation, as discussed later in this article. The standard for unrestricted irrigation in developing countries, as established by the World Health Organization (1989), calls for a maximum fecal coliform concentration of 1000/100 ml and a maximum concentration of helminthic eggs of 1 per litre. This can be achieved by lagooning with sufficient detention times (for example, one month in warm regions). The lagoon effluent will then also have greatly reduced concentrations of bacteria and viruses.

The WHO standards were based on public health effects as manifested by documented disease outbreaks (epidemiology), and feasibility of treatment system. Case histories of disease outbreaks due to irrigation with poorly treated wastewater showed that they were mainly caused by intestinal nematodes or parasitic worms (helminthic eggs such as Ascaris and Trichuris species and hookworm, where endemic). It was also concluded that presence of pathogenic organisms in the wastewater does not necessarily mean disease outbreaks, especially if the organisms are present in low concentrations and/or there is local immunity. On the other hand, the much more stringent California-type standards are based on avoiding presence of pathogens in the wastewater, regardless of whether they are capable of causing diseases or not, and the essentially complete elimination of such pathogens in the treatment process. This may be the preferred approach where such treatment is feasible, where the public demands zero or minimum risk, and where municipalities, irrigation districts, and farmers need to protect themselves against lawsuits in case of disease outbreaks where contaminated agricultural products are implied (Shelef, 1991). Another factor to consider is whether the crops will be entirely consumed by local people with built up immunities to certain diseases, or whether the crops will also be consumed by outsiders (visitors to the region or people in other regions to which the crops are exported). If the crops are also consumed by outsiders, the more stringent standards should apply.

Of course, all these comments apply to unrestricted irrigation, which includes irrigation of crops consumed raw or brought raw into the kitchen. For other crops (fiber and forage crops, orchards, etc.), the standards are less strict. In addition to public health considerations, agronomic factors should also be considered and the wastewater should meet the normal quality requirements (salinity, sodium adsorption ratio, nitrogen, toxic and trace elements, etc.) for irrigation water (Bouwer and Idelovitch, 1987, and references therein; Pettygrove and Asano, 1985).

MUNICIPAL USE

Where there is no irrigated agriculture near the city or where it is otherwise not feasible to use water for municipal purposes first and then for agricultural irrigation, cities will have to recycle their wastewater internally if they must meet increasing water demands but have no additional water resources. In dry climates, cities initially can get some relief of their water shortage problems by using wastewater for urban irrigation (parks, playgrounds, sports fields, golf courses, street and highway plantings, gardens, home yards, etc.). This requires treatment of the wastewater to the same standards used for unrestricted irrigation. Eventually, however, complete recycling, including potable use, may become necessary.

<u>Potable reuse</u>. Indirect recycling of municipal wastewater has, of course, been going on for ages along rivers that are used both for disposal of wastewater and for municipal water supply. If the pollution level in such rivers is moderate, cities are giving the water essentially conventional treatment (coagulation, sedimentation, sand filtration, and disinfection) before using it for drinking. If the pollution is severe, activated carbon adsorption is included, usually as powdered activated carbon added during the flocculation-sedimentation process. Sometimes, granular activated carbon adsorption, cascade aeration, and ozonation are also used. Where stream flows and/or water quality vary, surface storage of raw water may be desirable so that water can be stored during high flows with good dilution of pollutants for use during periods of low flows or other episodes when the river water is of low quality and should be avoided. This is done by the city of Rotterdam in The Netherlands (Kuyt, 1978). Some systems use bank filtration or other groundwater recharge and recovery systems to take advantage of the quality improvement obtained when wastewater or polluted water moves through soils and aquifers (see section on soil-aquifer treatment later in this article).

Direct recycling requires considerable treatment (advanced wastewater treatment or AWT) of the wastewater after conventional primary and secondary treatment. Normal drinking water standards cannot be used to determine if the water after AWT is suitable for drinking, because such standards apply only to situations where the water source is relatively unpolluted. Wastewater, however, contains many chemicals, perhaps hundreds or thousands, that enter the sewer system with residential and industrial discharges. Since it is practically impossible to develop maximum contaminant levels (MCLs) for all these chemicals in drinking water and to monitor for all these chemicals in the water after AWT, potable recycling of wastewater requires that the treatment processes be specified, rather than setting a multitude of MCLs for chemicals that may be in the product water. The AWT processes must then be tested in pilot or demonstration type projects where the suitability of the product water for drinking can be ascertained by chemical analyses, biomonitoring, and bioassays. For full-scale operations, only certain critical quality parameters then need to be monitored to make sure that the treatment processes are working correctly. Such pilot-demonstration type projects can also serve as public information centers to develop the proper community relations and to gain public acceptance. Without such acceptance, potable recycling of wastewater is impossible.

An example of a pilot/demonstration project is the Denver, Colorado, Potable Water Reuse Demonstration Project (Lauer, 1991). This project takes conventionally treated effluent (activated sludge, plus coagulation and sedimentation, and some denitrification) and converts it into drinking water with the following treatment train: lime clarification, recarbonation, granular media filtration, ultraviolet irradiation, granular activated carbon adsorption, reverse osmosis, air stripping, ozonation, and chloramination. These steps were selected to provide the necessary treatment, redundancy, and multiple barriers against the various contaminants. For example, bacteria and viruses are removed by lime clarification, ultraviolet irradiation, reverse osmosis, ozonation and chloramination. These processes, except chloramination, also remove protozoa. Organic compounds are removed by lime clarification, activated carbon adsorption, reverse osmosis, and air stripping. Except for air stripping, these processes also remove inorganic compounds, including metals. The total costs (amortization plus operation and maintenance) of this advanced treatment in August 1988 dollars and projected to a 0.4 million m^3/day plant were about \$600 per 1000 m^3 (personal communication, W. C. Lauer, 1990). To this amount must be added the costs of approximately \$100 per 1000 m^3 for the primary and secondary treatment.

An example of an operational facility is the El Paso, Texas, Water Recycling System. This system has a capacity of about 40,000 m^3/day and presently treats about 27,000 m^3/day. The treatment train consists of primary treatment, secondary treatment (aeration) with addition of powdered activated carbon, denitrification with addition of methanol as energy source, lime clarification, recarbonation, sand filtration, ozonation, and granular activated carbon adsorption. The water is then injected through wells into an aquifer, from where it is pumped for municipal use from production wells about 3 km downgradient from the injection wells. Projected underground travel times from the injection wells to the production wells were on the order of 2 to 4 years, but may actually be shorter due to faster flow through the more permeable layers of the aquifer. The total cost of the treatment process (excluding well injection) is about \$700/1000 m^3. Well injection, rather than groundwater recharge with infiltration basins, was selected for the El Paso project because the groundwater was relatively deep, undesirable chemicals could leach from the vadose zone, and the groundwater at the top of the aquifer was of poor quality. Thus, water after AWT was directly injected into the deeper layers of the aquifer system where the groundwater was of good quality. For additional discussion of the role of well injection and recovery from the aquifer in the recycling process, see the section Well Injection at the end of this article.

SOIL-AQUIFER TREATMENT WITH INFILTRATION SYSTEMS

Soil-aquifer treatment. When wastewater after primary or secondary treatment is used for groundwater recharge with infiltration basins, the quality of the water improves significantly as it moves downward through the vadose (unsaturated) zone to the groundwater and then laterally through the aquifer to the collection system (pumped wells, gravity subsurface drains, surface drains, gaining streams, etc.). These recharge systems require permeable soils to get adequate infiltration rates, vadose zones without restricting layers or other problems (contaminated zones, undesirable chemicals that can be leached out, etc.), and aquifers that are unconfined and have good quality groundwater at the top. Infiltration basins are intermittently flooded and periodically cleaned (Bouwer, 1991). Infiltration rates typically are of the order of a few dm/day during flooding but because of regular drying, long term average infiltration rates are more on the order of 50 to 100 m/yr. At these rates, one ha of infiltration basin can infiltrate 0.5 to 1 million m^3/yr.

When wastewater is used for groundwater recharge by surface infiltration, there are usually two objectives: (1) quality improvement of the water, and (2) seasonal or other storage in the aquifer. For these reasons, the recharge systems are designed and managed as recharge-recovery systems, using various layouts of infiltration basins and wells, drains, or other collection facilities (Bouwer, 1991). Since water quality improvement by filtration through the soil and aquifer often is the main objective, the systems are no longer called groundwater recharge systems but soil-aquifer treatment (SAT) systems. The performance of SAT systems is site dependent and controlled by wastewater quality, soils, hydrogeology, and climate. Thus, pilot or experimental systems should always precede full-scale and operational systems so that the feasibility of SAT can be evaluated and the full-scale system can be designed and managed for optimum performance.

Examples of such experimental and demonstration projects are the Flushing Meadows Project (Bouwer *et al.*, 1980) and the 23rd Avenue Project (Bouwer and Rice, 1984) in the Salt River floodplain west of Phoenix, Arizona. Both projects used secondary effluent (activated sludge) from Phoenix. Average quality parameters for the secondary effluent as it infiltrated the soil in the basins and of the water after SAT are shown in Table 1. The metal concentrations of the effluent in this table are recent values (personal communication, Pat Wokulich, Water and Wastewater Department, City of Phoenix, 1990). Recent metal concentrations in the water after SAT were not determined. However, analyses of samples about 20 years ago indicated much higher metal concentration in the secondary effluent and removal percentages in the SAT system of 84% for zinc, 87% for copper, 12% for cadmium, and 16% for lead (Bouwer *et al.*, 1980). Since the present metal concentrations in the wastewater, as shown in Table 1, are much lower, higher removal percentages can be expected. The vadose zone and aquifer in the 23rd Avenue Project consisted mainly of sand and gravel layers and the groundwater table was at a depth of about 17 m. There were four parallel infiltration basins totaling 16 ha. The well for pumping wastewater after SAT was located in the center of the basin area and was perforated from 30 to 55 m. The four basins of the project were operated on a schedule two weeks flooding-two weeks drying

TABLE 1 Quality parameters from Phoenix, Arizona, SAT system for mildly chlorinated secondary effluent (activated sludge) as it entered the infiltration basins (left column) and after SAT and pumping it from a well in the center of the infiltration basin area (right column).

	Secondary effluent mg/ℓ	Recovery well samples mg/ℓ
Total dissolved solids	750	790
Suspended solids	11	1
Ammonium nitrogen	16	0.1
Nitrate nitrogen	0.5	5.3
Organic nitrogen	1.5	0.1
Phosphate phosphorus	5.5	0.4
Fluoride	1.2	0.7
Boron	0.6	0.6
Biochemical oxygen demand	12	0
Total organic carbon	12	1.9
Zinc	0.036	
Copper	0.008	
Cadmium	0.0001	
Lead	0.002	
Fecal coliforms per 100 ml	3500	0.3
Viruses, PFU/100 ℓ	2118	0

to enhance denitrification in the soil and to allow recovery of infiltration rates between flooding periods. Infiltration rates during flooding were about 0.5 m/day but since the basins were dry about half the time, hydraulic loading rates were about 100 m/yr.

The quality parameters of the water after SAT in Table 1 show that the water meets the agronomic requirements for crop irrigation and the health standards for California Title 22 effluent (Bouwer, 1985; Bouwer and Idelovitch, 1987, and references therein). Hence, the water is suitable for unrestricted irrigation (including sprinkler irrigation of fruits and vegetables consumed raw or brought raw into the kitchen, and of parks and playgrounds) and for unrestricted aquatic recreation (including swimming and fishing). For potable use of the water after SAT, the quality parameters in Table 1 that need attention are total dissolved solids (790 mg/l), total organic carbon (1.9 mg/l) and fecal coliforms (0.3/100 ml). The salt concentration in the water is not excessively high, but higher than the maximum of 500 mg/l usually desired. The total organic carbon includes a wide spectrum of halogenated and non-halogenated aliphatic and aromatic compounds, many at concentrations on the order of 1 μg/l (E.J. Bouwer *et al.*, 1984). Also, the organic compounds probably include THM precursors like humic and fulvic acids. While fecal coliforms were very low and often zero, and viruses could never be detected in the water after SAT, the water should be disinfected to protect against possible breakthrough of pathogens.

Pilot studies would be needed to determine the best treatment of the water after SAT for potable use. Likely treatment steps include granular activated carbon adsorption, reverse osmosis (possibly on part of the flow), and chlorination or other disinfection. As membrane technologies continue to be improved, it may become more economical to delete the carbon adsorption and go to 100% reverse osmosis followed by disinfection. Costs (1988 U.S. dollars) of these post-treatment schemes for a 0.4 million m^3/day plant would be about \$230/1000 m^3 for carbon filtration, reverse osmosis on half the flow, and disinfection (personal communication, W. C. Lauer, 1990). The cost would increase to \$300/1000 m^3 if the carbon adsorption is deleted and the entire flow would go through reverse osmosis followed by disinfection. Thus, if secondary effluent first goes through a groundwater recharge system for SAT, the cost of treating it into drinking water is considerably less (about 50 to 60% less) than the \$600/1000 m^3 for complete AWT of secondary effluent.

SAT itself is relatively inexpensive and the cost often consists mainly of that for pumping the water from the aquifer, if wells are used for water recovery. This is about \$5/1000 m^3 if the groundwater is shallow (about 5 m lift) and \$50/1000 m^3 if it is deep (about 50 m lift). Other advantages of groundwater recharge and SAT systems are that they are robust and fail-safe and do not require highly skilled technical personnel for operation. Also, they offer underground storage to absorb seasonal or other differences between the supply of wastewater and the demand for water after SAT. This eliminates the need for expensive surface storage facilities. Thirdly, SAT systems break the pipe-to-pipe connection of the direct recycling of wastewater with in-plant treatment only. This enhances the aesthetic aspects and public acceptance of potable reuse of municipal wastewater, because the water is pumped from wells where it has lost its identity as sewage water. This can be of great importance in countries where there are religious or sociocultural objections to the use of wastewater.

Pretreatment

Before municipal wastewater is used for SAT, it usually receives conventional primary and secondary treatment, at least in the United States where such treatment is required to meet discharge permit requirements. However, since SAT systems can remove a lot more BOD than is in secondary effluent, secondary treatment really is not necessary where the effluent is used for groundwater recharge and SAT. As a matter of fact, the higher organic carbon content of primary effluent actually may enhance nitrogen removal by denitrification in the SAT system (Lance *et al.*, 1980). Also, it may enhance removal of synthetic organic compounds by stimulating greater biological activity in the soil and resulting increase in co-metabolism and secondary utilization (McCarty *et al.*, 1984). Where primary effluent has been used for SAT systems, satisfactory results have generally been obtained (Carlson *et al.*, 1982; Lance *et al.*, 1980; Rice and Bouwer, 1984). Since the total cost of primary and secondary treatment in a large plant (0.4 million m^3 per day, for example) may be about \$80 per 1000 m^3, elimination of the secondary treatment step would save about \$40 per 1000 m^3, thus increasing the value of SAT by another \$40 per 1000 m^3. This estimate is based on the assumption that the cost of primary treatment is about the same as the cost of secondary treatment. Secondary treatment requires a lot more energy and could be more expensive than primary treatment, but the cost of sludge handling and disposal in the primary treatment can also be high, depending on local conditions. Since primary effluent generally has a higher suspended solids content than secondary effluent, hydraulic loading rates of the infiltration basins may be lower and they may have to be cleaned more often. This increases the cost of SAT.

Other treatment methods prior to groundwater recharge and SAT could be lagooning, overland flow, wetlands, or similar "natural" method that is not "high-tech." Infiltration problems, however, could arise if the water from these treatment processes contains a lot of suspended algae because these can form a filter cake or clogging layer on the bottom of the infiltration basins for the SAT system. The infiltration basins then should be shallow to avoid compaction of the clogging layer and to promote rapid turnover of the water in the basins to minimize additional algae growth (Bouwer and Rice, 1989).

WELL INJECTION

Where SAT with infiltration systems is not feasible because surface soils and/or vadose zones are unsuitable or aquifers have poor quality water at the top or are confined, groundwater recharge can be achieved with injection wells. Since aquifer materials often are relatively coarse, the treatment benefits of flow of wastewater through an aquifer tend to be small. Also, to prevent clogging of the aquifer interface around the recharge well, the water should first be treated to remove all suspended solids, BOD, nutrients, and microorganisms. A residual chlorine content is also necessary to minimize bio-clogging of the well and aquifer. Thus, wastewater for well injection should be treated to essentially drinking water standards before it goes into the well. This makes groundwater recharge through wells much more expensive than recharge with infiltration basins. However, the recharge process with wells still offers the benefits of storage in the aquifer, enhanced aesthetics and public acceptance for potable reuse of the water (no pipe-to-pipe connection), and the polishing treatment obtained in the aquifer. To maximize the latter, production wells should be a significant distance (1 km or more, for example) from injection wells to allow for sufficient distance and time of underground travel. An example of the sequence of advanced wastewater treatment-injection wells-pumped wells is the system used by the city of El Paso, Texas, as discussed earlier in this article.

CONCLUSIONS

Water reuse will become increasingly important, especially in water-short areas. Municipal wastewater typically can be used for irrigation (agricultural crops, parks, golf courses, landscaping, etc.) and for potable recycling, directly or indirectly. Water quality standards for unrestricted crop irrigation are stricter for developed countries than for developing countries. For potable recycling, advanced wastewater treatment (AWT) processes must be specified rather than maximum contaminant levels for the myriad of chemicals that can be in municipal wastewater. If conventionally treated wastewater is used for groundwater recharge and pumped up as renovated water from the aquifer, some of the AWT steps can be deleted. This reduces the total treatment costs for potable recycling by about 50%. Groundwater recharge and recovery systems also provide seasonal or other storage of the water, and they enhance the aesthetics and public acceptance of potable recycling by breaking the pipe-to-pipe connection of complete in-plant AWT.

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